

ENERGY CONSERVATION

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HEAT INSULATION OF HIGH-TEMPERATURE HEATING UNITS FOR CERAMIC PRODUCTION

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Heat losses are studied for a tunnel furnace used for firing porcelain and refractory materials. Calculations of the heat losses through the arch of the furnace are performed using diatomaceous crumb and granulated foam glass ceramic as heat-insulating fill. Cost-effectiveness calculations show that there is an advantage to using granulated foam glass ceramic.

Key words: heating units, firing of a ceramic, heat insulation, diatomaceous crumb, granulated foam glass ceramic, cost-effectiveness.

One of the main problems in the development of the Russian economy is fuel-energy resource conservation. In the solving this energy conservation problem priority is given to high-efficiency industrial heat insulation. Heat insulation is used in practically all industries — petroleum processing, metallurgy, food, light, and so on.

In light industry the objects of heat insulation are high-temperature furnaces for firing porcelain and other articles, water heating and steam boilers, gas lines, heat-exchangers, hot water tanks, exhaust stacks, exhausters, and pipelines. Especially high requirements are imposed on the efficiency of heat insulation for furnaces of the first, second, and decorative firing. Here attention must be given to the fact that the expenditures on process fuel in the industry are 20–40% of the production costs (depending on the type of fuel, temperature regime, type of furnace, and geographic location of the enterprise).

Porcelain and ceramic articles are produced, using high-temperature technologies, in oxidizing and reducing gas media. Furnaces with a similar construction are used for manufacturing refractory and construction brick.

Thermophysical characteristics of a tunnel furnace (94 × 1.3 m) for the second firing of porcelain articles

| | |
|---|-----------|
| Maximum firing temperature, °C | 1410 |
| Heat consumption, W | 2,788,800 |
| Heat release in the workshop, W | 697,200 |

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Evidently, the heat release in a manufacturing unit is 25% of the heat consumption, and a considerable fraction of the heat losses occur at the walls and arch of the furnace.

For high firing temperatures, corresponding requirements are imposed on the heat insulation for furnaces. The energy efficiency of the operation of the commercial equipment, the adherence to prescribed process regimes, and in consequence production quality and costs all depend on the correct choice of the heat insulation. Thus, low heat-insulation efficiency has a large effect on the heat balance of the furnace and results in inefficient use of fuel-energy resources.

This problem became urgent for enterprises with energy-intensive technologies, since the continual growth of energy-carrier prices affects the pricing policy of commercial enterprises and their survival under modern economic conditions.

The heat insulation of furnaces, aside from conserving energy and securing the process regimes, makes it possible to create safe working conditions and increase the sanitary and ecological level of the production process.

The requirements imposed on the heat insulation materials are determined by the quality of mounting, conditions of use, technological routines, and maintenance. The internal and external temperature of the masonry, the changes in the moisture content of the external medium, the mechanical actions, and the possibility of recycling such materials during major and routine maintenance are all taken into account.

The main indicators characterizing the physical-technical and operating properties of the heat-insulation materials are the thermal conductivity, density, temperature stability, com-

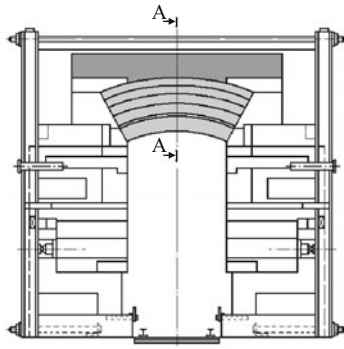


Fig. 1. Tunnel furnace (94 × 1.3 m).

pression strength, shape stability, fire-resistance, water-resistance, and resistance to chemically corrosive media [1].

The thickness of the heat-insulation layer is determined by the thermal conductivity of the material, and since it depends on the temperature, which changes according to a prescribed regime in the course of firing, the thickness of the masonry walls and arch vary correspondingly along the furnace. Taking account of this, when choosing heat insulation special attention is given to the thermophysical and strength characteristics of the object being insulated and the computed admissible loads on the supports and other elements of the insulated surface.

The present work examines the problem of heat losses through the arch for a tunnel furnace (94 × 1.3 m) (Fig. 1) used in the manufacturing of porcelain and refractory materials.

Main parameters of a tunnel furnace (94 × 1.3 m)

| | |
|--|-------|
| Length, m: | |
| total | 94.00 |
| furnace channel | 94.00 |
| Width, m: | |
| total | 4.06 |
| channel | 1.30 |
| Height, m: | |
| total | 3.60 |
| channel in the arch keystone | 2.59 |
| channel at the arch impost | 2.37 |
| Wall thickness in the firing zone, m | 1.38 |

In the design of a porcelain manufacturing plant light-weight fireclay brick, diatomaceous brick, and diatomaceous crumb were used as heat insulation in the arch of the tunnel furnace (Table 1).

We have performed calculations of the heat losses through the arch of tunnel furnace using diatomaceous crumb and PSK 200 granulated foam glass ceramic developed by “Tomtekhnnologiya” JSC as a filler material. The thicknesses of the refractory and heat-insulation layers of the furnace arch in the variants studied correspond to the design data and are calculated so as to minimize the heat release into the environment, the temperature differential between the outer and inner surfaces of the furnace, and taking account of the thermophysical properties of the materials.

We shall determine the heat losses through the arch of a tunnel furnace under the following conditions:

maximum firing temperature 1320°C;

temperature at all points of the arch of the furnace constant in time, i.e., the temperature field is a function of the coordinates only;

steady heat transfer; and,

stationary heat flux.

The amount of heat flowing with stationary flux through a section in 1 h is

$$Q = F_i \frac{t_1 - t_{n+1}}{\frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \dots + \frac{\delta_n}{\lambda_n}},$$

where F_i is the area of the i th position, m^2 ; i is the position number, $i = 1 - 49$; t_1 and t_{n+1} are, respectively, the surface temperature of the inner and outer masonry of the furnace, °C; δ is the thickness of a layer, m; λ is the thermal conductivity of the refractory material, $W/(m \cdot K)$; and, n is the number of the heat-insulation layer.

The thermophysical characteristics of the materials presented in Table 2 were used in the calculations. Granulated foam glass ceramic with usage temperature 650°C as the filler material in the furnace arch can be used since the temperature at the interface of the fireclay light-weight brick and diatomaceous crumb (Fig. 2) is in the range 400 – 480°C.

Figure 2 presents a temperature regime of the second firing of porcelain which reveals three characteristic sections that differ in the thickness of heat insulation of the furnace roof and type of the refractory material:

Section 1 — fireclay brick (positions 3 – 18) temperature range 300 – 1080°C;

Section 2 — dinas brick (positions 18 – 31) temperature range 1080 – 1320 – 900°C;

TABLE 1.

| Name | Material | Type | Class | Total mass, kg |
|-----------------------------------|---|-------|-----------|----------------|
| Brick with lineal dimensions, mm: | | | | |
| 230 × 114 × 65 | Light-weight fireclay | No. 5 | ShLB-1.0 | 94,500 |
| 230 × 114 × 65 | Diatomaceous (tripoli type) brick | K-2 | Grade 700 | 18,000 |
| Arch fill | Diatomaceous crumb with density 350 kg/m ³ | — | — | 27,000 |

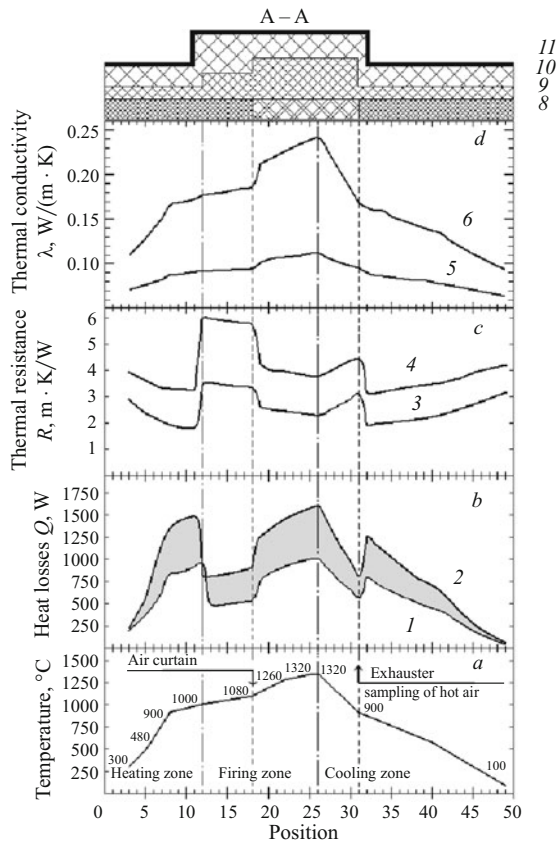


Fig. 2. Variation of the thermophysical characteristics over the longitudinal section of the arch of the working channel in a tunnel furnace using as filler diatomaceous crumb and granulated foam glass ceramic: *a*) temperature regime of the furnace; *b*) heat losses; *c*) thermal resistance of the arch; *d*) thermal conductivity; 1, 4, 5) granulated foam glass ceramic; 2, 3, 6) diatomaceous crumb; arch of a tunnel furnace along the section A – A: 7) dinas brick; 8) fireclay brick; 9) fireclay light-weight brick; 10) diatomaceous crumb (variant I); 11) red brick.

Section 3 — fireclay brick (positions 31 – 49) temperature range 900 – 100°C.

The total heat losses through the arch of a tunnel furnace with the use of diatomaceous earth (variant I) and granulated foam glass ceramic (variant II) were determined as a sum of the heat losses through arch at each position. The thermal conductivity of the layers as a function of the material used was calculated according to the following relations [2, 3, 4]:

fireclay refractory brick:

$$\lambda = 0.84 + 0.580 \times 10^{-3} t_{av};$$

fireclay light-weight brick:

$$\lambda = 0.41 + 3.5 \times 10^{-4} t_{av};$$

diatomaceous crumb:

$$\lambda = 0.079 + 2.6 \times 10^{-4} t_{av};$$

dinas brick:

$$\lambda = 0.93 + 0.69 \times 10^{-3} t_{av};$$

granulated foam glass ceramic:

$$\lambda = 0.059 + 0.00016 t_{av},$$

where t_{av} is the average temperature, °C.

To determine the thermophysical characteristics of the variants I and II the calculations were performed without heat losses through the masonry walls and the masonry of the furnace cars. Calculations performed for the three sections of the arch of a tunnel furnace show that replacing diatomaceous crumb by granulated foam glass ceramic reduces heat losses by 14,925 W [5, 6]. The heat losses through the arch of a tunnel furnace are presented in Table 3.

The granulated foam glass ceramic makes it possible not only to decrease the heat losses but also to decrease the load on the arch and walls of the furnace substantially.

Heat transfer through the arch of the tunnel furnace is characterized by a change in a number of parameters of the heat-insulation and refractory materials: the nature of the materials with different temperature dependences of the thermal conductivity $\lambda = f(t)$; the thickness of the layers of the materials; and, the temperature of the inner surface of the masonry of the furnace.

A following parameter that represents the total thermal resistance R was used to determine the character of the effect of such parameters on the heat losses through the arch:

$$R = \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \dots + \frac{\delta_n}{\lambda_n}.$$

The total thermal resistance is a complex parameter that characterizes a multilayer wall as a function of the layer

TABLE 2.

| Indicator | Foam glass ceramic PSK 200 | Fireclay lightweight brick ShLB-1.0 | Diatomaceous brick | Diatomaceous crumb |
|-------------------------------|-------------------------------|--|-----------------------|-----------------------|
| Density, kg/m ³ | 200 – 300 | 1000 | 500 | 350 |
| Thermal conductivity, W/(m·K) | 0.062 | 0.417 | 0.089 | 0.084 |
| Compression strength, MPa | 0.80 – 3.00 | 2.94 | 1.00 – 1.50 | – |
| Usage temperature, °C | from – 40 to + 650 | 1250 | 1000 | 1000 |

TABLE 3.

| Variant | Heat losses Q^* , W | | | |
|---------|-------------------------------|-----------|-----------|-----------|
| | Q_1 | Q_2 | Q_3 | Q_{tot} |
| I | Diatomaceous crumb | | | |
| | 13,485.30 | 16,995.00 | 11,342.50 | 42,693.90 |
| II | Granulated foam glass ceramic | | | |
| | 9419.35 | 10,936.60 | 7412.85 | 27,768.80 |

* Q_1 , Q_2 , and Q_3 are the heat losses through the furnace arch on sections 1, 2, and 3, respectively; Q_{tot} total heat losses through the arch of the tunnel furnace.

TABLE 4.

| Heat-insulating material | Cost, rubles | | |
|--------------------------|------------------|----------------------|---------|
| | 1 m ³ | 42.25 m ³ | savings |
| Diatomaceous crumb | 7200 | 304,200 | — |
| PSK 200 | 1300 | 54,925 | 249,275 |

* Amount of heat insulating material filled in.

thickness and thermal conductivity of the material and equals the sum of the thermal resistances of each layer. When diatomaceous crumb and PSK 200 foam glass ceramic are used, the thermal conductivity depends on the temperature of each position in the range 0.093 – 0.242 W/(m · K) and 0.065 – 0.113 W/(m · K), respectively (see Fig. 2d).

In consequence, the total thermal resistance along the furnace for foam glass ceramic is much higher than for diatomaceous crumb at the temperatures studied (see Fig. 2c).

The calculations of the effectiveness of PSK 200 foam glass ceramic as a bulk heat insulating material at the stage

of operation and construction are presented below and in Table 4.

Heat-producing effect of the fuel, kJ/kg:

M100 fuel oil 40,800
natural gas 36,065

Heat losses through the arch, W:

diatomaceous crumb Q_1 42,693.9
PSK 200 foam glass ceramic Q_2 27,768.8

Fuel conservation:

M100 fuel oil, tons/year. 11.388
natural gas, m³/year 13,052

Cost, rubles:

M100 fuel oil 69,466
natural gas 44,366

The mechanical strength of the granulated foam glass ceramic (see Table 2) permits recycling this material during routine and major maintenance.

In summary, the use of foam glass ceramic as a filler material makes it possible to meet the requirements of the process routine and operate the heating unit with a substantially lower consumption of fuel – energy resources and material expenditures during construction and repair work.

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